1. INTRODUCTION

Automotive Lightweighting Materials R&D

As a major component of the U.S. Department of Energy's (DOE's) Office of FreedomCAR and Vehicle Technologies Program (FCVT), Automotive Lightweighting Materials (ALM) focuses on the development and validation of advanced materials and manufacturing technologies to significantly reduce automotive vehicle body and chassis weight without compromising other attributes such as safety, performance, recyclability, and cost.

The specific goals of ALM are to develop material and manufacturing technologies by 2010 that, if implemented in high volume, could cost-effectively reduce the weight of light-duty body and chassis systems by 50% with safety, performance, and recyclability comparable to 2002 vehicles.

ALM is pursuing five areas of research: cost reduction, manufacturability, design data and test methodologies, joining, and recycling and repair. The current Long-Range Plan for activities in these areas during the next 5 years is found at www.eere.enrgy.gov. Because the single greatest barrier to use of light-weight materials is their high cost, priority is given to activities aimed at reducing costs through development of new materials, forming technologies, and manufacturing processes. Priority lightweighting materials include advanced high-strength steels (AHSSs), aluminum, magnesium, titanium, and composites including metal-matrix materials and glass- and carbon-fiber-reinforced thermosets and thermoplastics. The inclusion of AHSSs is an example explaining the term "lightweighting" as opposed to just "lightweight" in order not to imply focus on just lower density materials.

Collaboration and Cooperation

ALM collaborates and cooperates extensively to identify and select its research and development (R&D) activities and to leverage those activities with others. The primary interfaces have been and still are with the Big Three domestic automotive manufacturers, namely the FreedomCAR Materials Technical Team, the Automotive Composites Consortium (ACC), and the United States Automotive Materials Partnership (USAMP). This collaboration provides the means to determine critical needs, to identify technical barriers, and to select and prioritize projects. Other prominent partners include such organizations as the American Iron and Steel Institute, the American Plastics Council, the Vehicle Recycling Partnership, and the International Magnesium Association. ALM also coordinates its R&D activities with entities of other U.S. and Canadian federal agencies. Interactions with the DOE Office of Industrial Technologies Program (ITP), FCVT's High-Strength Weight Reduction (HSWR) Materials effort, and the Department of Natural Resources of Canada (NRCAN) are especially important by virtue of overlaps of interests in lightweight materials. Contacts with similar efforts in other countries besides Canada are being pursued. Joint planning was done in FY 2004 with the U.S. National Science Foundation, and one project was jointly funded with the DOE Office of Science.

Project Selection and Stages

In cooperation with USAMP and the FreedomCAR Materials Technical Team, a procedure has been established to help facilitate the development of projects in order to help move high-risk leveraged research to targeted research projects that eventually migrate to the original equipment manufacturers (OEMs) or suppliers as application engineering projects. Technology research projects are assigned to one of three phases as depicted in the figure on the next page: concept feasibility, technical feasibility, and demonstrated feasibility. Projects are guided to meet the requirements of each phase before they are allowed to move on to the next phase. Definitions of the phases follow:

Concept Feasibility: Concept feasibility projects should contain a specific idea to address a need or to create something new. Projects are usually exploratory, small in monetary requirements, and short in length. Projects should provide a yes/no answer to the value of the idea. All projects are required to have a detailed research plan, budget, and timing. These projects are typically less than $200,000 and have a duration of 1–2 years. They can be ended before proceeding to technical feasibility if there is a lack of technical progress or if the preliminary business case turns out to be unfavorable. Successful concept feasibility projects can develop into technical feasibility projects.

Technical Feasibility: Technical feasibility projects should continue R&D for ideas with proven merit or potential. These projects should identify the key barriers to implementing the technology and focus on overcoming them. Technical feasibility projects should have well-defined OEM/industry supplier participation and pull. They are usually larger, longer term projects than the concept feasibility projects with typical research investment in the $1M to $2M range and length of 2–3 years. Technical feasibility projects can be ended before proceeding to demonstrated feasibility if there is a failure to overcome the key barriers to implementation or if the cost or business case does not develop as favorably as initially assessed.

Demonstrated Feasibility: Technology projects that need larger scale validation may become demonstrated feasibility projects. Not all technical feasibility projects will need a demonstration or validation program. These projects are few in number, much larger in scale, and may involve component or system fabrication and test. Support and leverage from the OEMs/industry is a key requirement for these projects.

Stage progression for project selection

Once selected, R&D projects are pursued through a variety of mechanisms, including cooperative research and development agreements (CRADAs), cooperative agreements, university grants, R&D subcontracts, and directed research. This flexibility allows the program to select the most appropriate partners to perform critical tasks. The ALM efforts are conducted in partnership with automobile manufacturers, materials suppliers, national laboratories, universities, and other nonprofit technology organizations. These interactions provide a direct route for implementing newly developed materials and technologies. Laboratories include Argonne National Laboratory (ANL), Lawrence Berkeley National Laboratory (LBNL), Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), Oak Ridge National Laboratory (ORNL), Pacific Northwest National Laboratory (PNNL), and Sandia National Laboratories (SNL). PNNL manages the Northwest Alliance for Transportation Technologies, drawing on expertise and developments in the Northwest. ANL oversees recycling efforts and ORNL provides overall technical support and coordination, including for the DOE cooperative agreement with USAMP. The National Engineering Technology Laboratory (NETL) provides overall projects management.

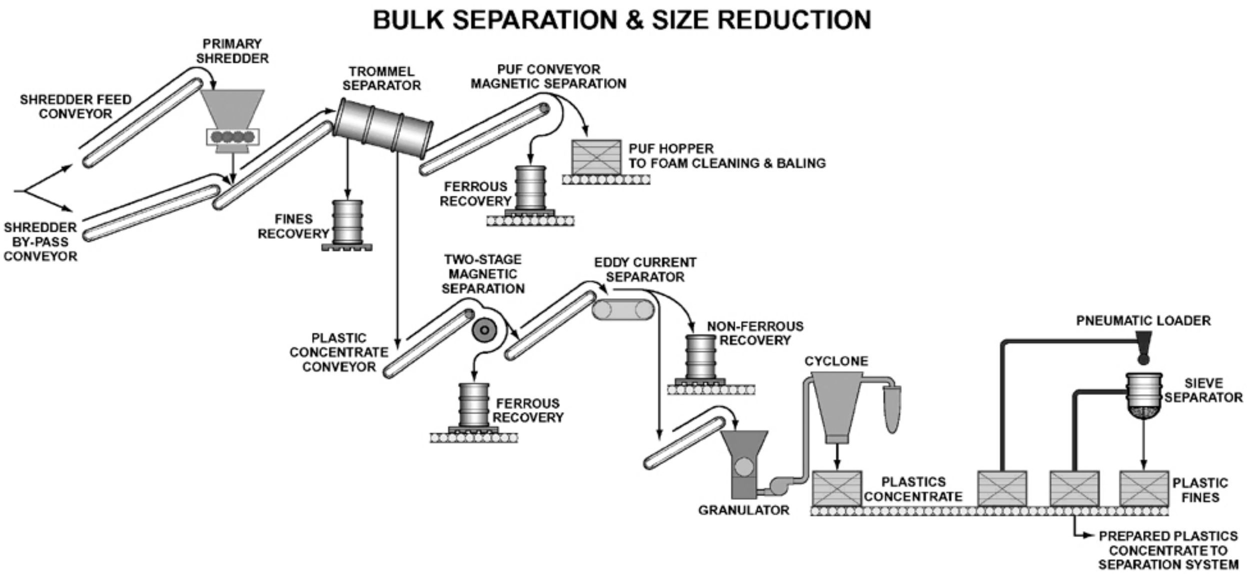
Research areas and responsible organizations

Coordinated area	Organization
Production and fabrication of aluminum	HSWR, ITP, Natural Resources of Canada (NRCAN)
Production and fabrication of magnesium	International Magnesium Association, NRCAN, HSWR
Recycling, reuse, repair of automotive parts and materials	Vehicle Recycling Partnership, American Plastics Council
Fabrication of steel and cast iron	American Iron and Steel Institute, the Auto/Steel Partnership, HSWR
Fundamental materials research	DOE Office of Science, National Science Foundation
High-volume composite processing	Department of Commerce—National Institute of Standards and Technology's Advanced Technology Program
Materials research for defense applications	Department of Defense
Materials research for space applications	National Aeronautics and Space Administration
Crashworthiness	Department of Transportation
International vehicle material R&D	International Energy Agency
Production and fabrication of composites	American Plastics Council

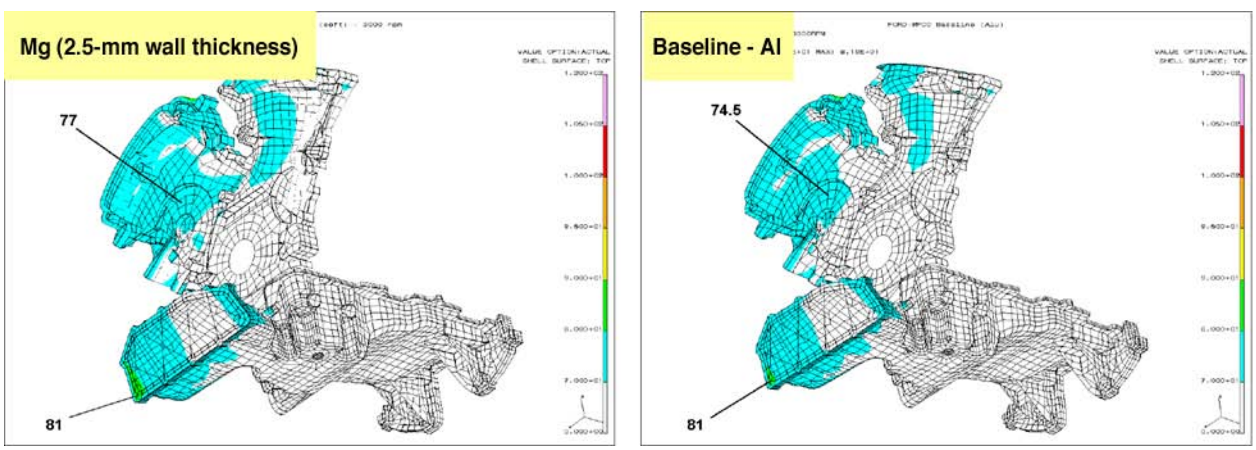
FY 2004 Accomplishments

Recyclability is one of the five major R&D areas for the ALM. Recyclability of end-of-life vehicles (ELV) is presently limited by the lack of commercially proven technical capabilities to cost-effectively separate, identify, and sort materials and components and by the lack of profitable post-use markets. The automobile of the future will use significantly greater amounts of lightweight materials (e.g., advanced high-strength steels, aluminum, magnesium, plastics, and both metal- and polymer-based composites) and more sophisticated/
complex components (e.g., fuel cells). Researchers at ANL, in collaboration with the Vehicle Recycling Partnership and technology developers, are working to develop and demonstrate technology for the cost-effect recovery of materials from post-shred residues. A pilot plant for the processing of raw shredder residue was completed in early 2004. Various recovery technologies are being evaluated to determine the performance (e.g., yield, purity, efficiency and cost) so that an optimized and integrated process for recovering materials from shredder residue can be developed. In related projects, ANL is demonstrating the feasibility of materials recovery for reuse in automotive and other applications, chemical conversion of residue to fuels and chemicals, and energy recovery.

Magnesium is the lowest density structural metal, 30% less dense than aluminum. Magnesium components are envisioned to replace an equivalent volume of ferrous material with a mass reduction of 70–75% and aluminum with a reduction of 25–35%. Significant progress was shown by a USAMP team working on a project to demonstrate and enhance the feasibility and benefits of using magnesium alloys in place of aluminum in structural powertrain components. During 2004, the team has made excellent progress. Project accomplishments include the development and distribution of a comprehensive engineering property database for the high-temperature, creep-resistant magnesium alloys identified for use in the project; the selection of the appropriate alloys for the magnesium-intensive engine components (engine block, structural oil pan, and front engine cover); completion of the design and cost model to predict the cost-effective performance of the engine; and the selection and initiation of basic research projects to develop the understanding to fully implement magnesium alloys in powertrain applications.



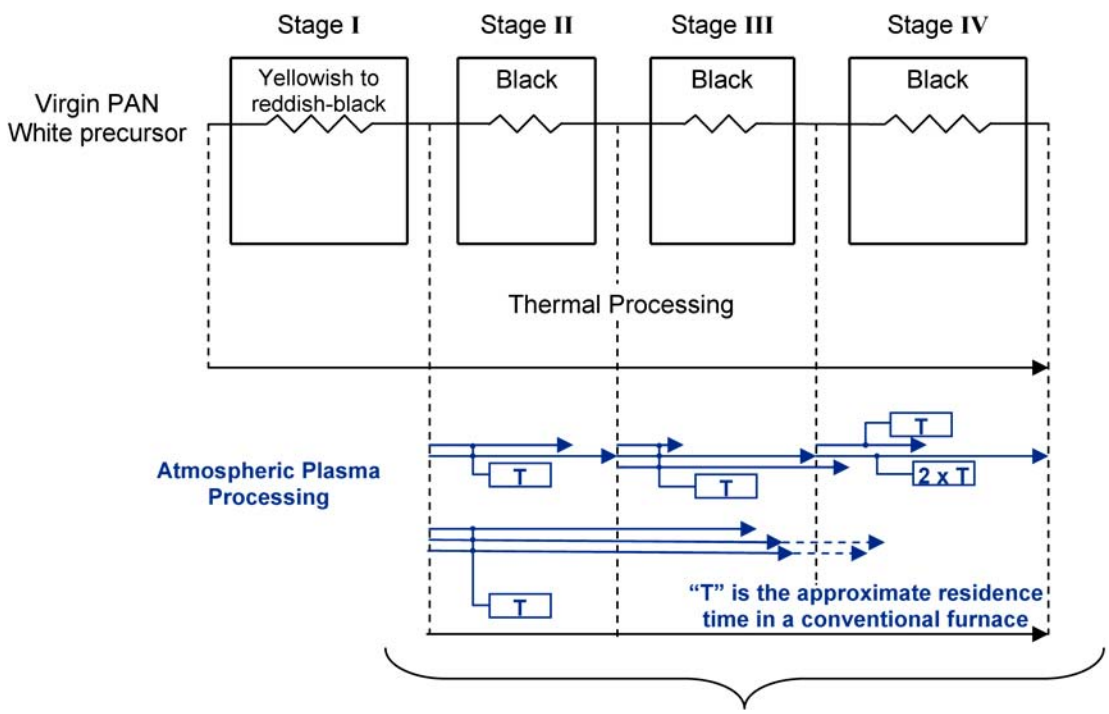
Schematic of the Argonne Pilot Mechanical Separation System for processing raw shredder residue.



NVH (noise-vibration-harshness) analysis of the structural oil pan and front engine cover for octave band 250 Hz at 3000 rpm, comparing the soft magnesium design with the aluminum baseline.

Aluminum metal matrix composites (MMCs) possess both lightweight and high wear-resistance characteristics, making them desirable for a number of body, chassis, and powertrain applications, provided that performance and cost objectives can be reached. However, several barriers, including cost, durability, and manufacturability, have hindered the widespread use of these materials. With the overall goal of demonstrating cost-competitive aluminum MMC options for structural and powertrain components in general, PNNL, in collaboration with MC-21, USCAR, Visteon and others, focused efforts on a brake rotor as a target application. A lightweight rotor that is 60% lighter than a conventional four-door luxury sedan cast iron rotor was designed and manufactured. Initial phases of the project developed a lower cost material and a low-cost process for producing it. The thermal and structural properties of the new material were evaluated and found to be acceptable. More recently, a low cost manufacturing process was selected, and prototype full-scale, fully reinforced brake rotors were produced and dyno tested. The rotor performance meets the braking requirements, with some future work still needed on friction materials to minimize noise and extend pad life. Work is ongoing to evaluate machining and tool life. The cost of the prototype rotor is estimated to be 1.5 times the cost of a cast iron rotor, compared to a figure of three times for prior aluminum MMC rotors.

Carbon-fiber-reinforced polymer-matrix composites (CFRPMCs) offer the potential to reduce vehicle weight by 50%. However, cost is a significant barrier to future implementation. Oxidative stabilization of polyacrylonitrile (PAN) precursor is a slow thermal process that typically consumes 70% or more of the processing time in a conventional carbon-fiber conversion line. ORNL is working on a rapid oxidation process that could dramatically increase the conversion line throughput and appreciably lower the fiber cost. They have demonstrated the ability, in atmospheric pressure plasma, to oxidize fiber in stages equivalent to conventional oxidation furnaces, identified key process parameters, modified the reactor to achieve stable operation, and identified the preferred range of feed gas compositions. Preliminary data suggest that the plasma oxidation process may allow earlier onset of carbonization, thus reducing oxidation residence even further. Early economic studies support the value of the research in reducing cost. Continued efforts will focus on continuous plasma processing of multitow precursors and characterization of fiber properties.



Schematic of conventional thermal oxidation process and progress in plasma oxidation process.

In addition to mass reduction, design optimization, high-volume manufacturing, and recycling, two key issues that need to be addressed are joining and crash energy management. ORNL is working to develop a comprehensive experimental and analytical methodology to analyze and design adhesively bonded automotive composite structures to sustain axial, off-axis, and lateral crash loads. The focus of the project is to develop the understanding of how critical joint design parameters affect the energy absorption. Significant progress has been made in characterizing the static response of bulk adhesive and braided carbon fiber substrates. In addition, preliminary dynamic stability tests on both bonded and unbonded tubes have been completed using the Test Machine for Automotive Crashworthiness (TMAC). The experimental results will be correlated with analytical results by developing finite-element-based tools with appropriate material models and progressive damage algorithms. The results of this project will be closely integrated with the experimental and analytical efforts undertaken by USCAR's Automotive Composites Consortium (ACC).

Future Direction

In FY 2002 and FY 2003, the FreedomCAR and Fuels Initiative formed from the 1994–2001 Partnership for a New Generation of Vehicles (PNGV) and thinking and planning on what replaces the ALM efforts that began in the PNGV in roughly 1999–2002, has continued since. The ALM and the FreedomCAR Materials Technical Team conducted a series of strategic reviews of various materials and manufacturing topics in FY 2004. Based on those reviews, CFRPMCs and magnesium will certainly be emphasized in the next few years as they have the greatest weight-reduction potential, but there will be some efforts on AHSSs, titanium, and metal–matrix composites because these will contribute in niche roles to the overall FreedomCAR weight-reduction and cost neutrality goals. Material-crosscutting work in general manufacturing will continue to increase in joining, nondestructive evaluation, and recycling. Though technical feasibility projects will dominate as before, base-technology, concept-feasibility and demonstrated-feasibility projects will also be pursued.